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No. 532

WELDING OF STAINLESS MATERIALS

By H. Bull and Lawrence Johnson

From Industrial Gases, March and June, 1928

Washington
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 532.

WELDING OF STAINLESS MATERIALS.*

By H. Bull and Lawrence Johnson.**

It is believed that this broad survey of the subject, giving particular attention to welding, should be of great assistance to the aircraft industry in this country. It would appear that welds in some stainless steels, heat-treated in some practicable way, will probably be found to have all the resistance to corrosion that is required for aircraft. Certainly these structures are not subjected to the severe conditions that are found in chemical plants.

This article should be considered as an outline of what can be done, not necessarily as instructions, which will enable anyone to obtain satisfactory results in commercial work. Before any aircraft manufacturer undertakes to make his structures by welding stainless steels he should provide competent metallurgical supervision, preferably by persons who have had extensive experience in handling these new steels.

NATIONAL ADVISORY COMMITTEE
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The above title has been chosen advisedly. The impression that stainless steel is a material of one composition or set of properties is wrong. It would be more correct to say that the

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Paper read at a meeting of the British Acetylene and Welding Association, London, March, 1928.

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layman's expression "stainless steel" now covers a range of steels in which the essential element chromium may vary from about 8 to 30 per cent, and which may also contain up to about 30 per cent nickel, together with smaller amounts of other metals.

The introduction of stainless steel in 1912-13 and the manufacture of knives by Sheffield cutlers, was really the first step in the production of a large range of alloys, comparable in extent with the range of ordinary steels, with which many are more familiar. When speaking of ordinary steel, it is usual to refer to dead soft or mild steel, axle steel, spring steel, tool steels, and so on. In just the same way today, we may refer to stainless steels. The first stainless steel knives were made of material similar to tool steels, but following engineers' demands, modification of composition resulted in material much softer than the cutlery quality being produced. After this still milder qualities resulted in what are known as the stainless irons. Thus the engineers today have a choice of material with a wide range of physical properties. Figure 1 shows diagrammatically the mechanical properties of hard stainless steel. Figure 2 shows the mechanical properties of hard stainless iron.

It may be noted that the above steels are such as may be

hardened and tempered to give desired physical properties. They are alloys of iron and chromium with varying amounts of carbon. With a given chromium content the carbon content determines whether the steel is of the mild or hard class (just as for carbon steels). All the steels in this class may be welded; the more easily the lower the carbon content. The hard variety (.30/.35 per cent carbon) made into cutlery is often welded, the knife blade and bolster is made of stainless steel and the handle of mild steel. The two are butt-welded just behind the bolster, and the handle afterwards silver-plated.

The milder qualities, which weld more readily, were produced to meet a demand for a material which could be worked more easily than the parent cutlery quality. Low carbon material is easier to work in the forge, and also when cold, i.e., for drawing and pressing. Further, and this is important for the welder, the low carbon material does not harden so intensively when cooled in the air from high temperatures.

Reference to Figure 3 shows graphically the behavior of the hard and mild stainless steels when cooled in air from varied temperatures. Cooled from a temperature of 1200°C , the hard stainless steel has a Brinell hardness of $512 = 112$ tons per square inch, while the milder material has only a Brinell hardness of $248 = 54$ tons per square inch.

The importance of this observation may be seen by reference to the turbine industry. The practice of some makers of

steam turbines is to cast the retaining ring and the center of cast iron in a mould into which the stainless blades have been placed in the position they are to occupy in the machine. During the casting operation, the blades are, of course, heated to a temperature in the neighborhood of the melting point of cast iron, and hence the physical properties of these blades after the operation will depend on the effect of this heating and the subsequent rate of cooling from that temperature. It would be expected from Figure 3 that the higher carbon stainless steel would be hardened by this treatment and consequently would become more or less brittle, and such was the case. For test purposes, a series of strips of stainless steel of different carbon content were embedded in this way in a block of cast iron (see Fig. 4). The strips of hard stainless steel broke off after bending only a few degrees.

On the other hand, a mild stainless steel treated in exactly the same manner did not harden to such a great extent and the strips could be bent at right angles as indicated by the dotted lines, without showing signs of fracture.

Other makers of turbines prefer to weld the blades into the retaining ring by the oxyacetylene process as illustrated in Figure 5.

Somewhat similar conditions as regards heating and cooling apply here as in the previous manufacturing process, and unless sufficiently mild material is used there is a distinct possibil-

ity of failure during service, owing to the brittleness of the material at the root of the blades.

It is seen that the turbine manufacturers got over their difficulties by selection of material. A better method would be to heat-treat the whole of the material after welding, providing it is practicable. Reheating to 700°C would soften the material and thereby remove the hardness induced by the rapid cooling from high temperatures. But removal of hardness is not the whole story; all commercial welding involves heating the parts to be welded to a high temperature, usually approaching the melting point of the material. When metals are heated to high temperatures the grains or crystals grow to an extent depending on the temperature as indicated diagrammatically in Figure 6. In the coarse crystalline condition metals are usually physically weak, and not very resistant to shock, even though they are soft. If the metal is air-hardening steel like hard stainless steel it will be even less tough, because the coarse grain size is coupled with hardness.

The coarse structure may be removed by suitable heat-treatment, usually referred to as normalizing in the case of carbon steels, which do not air-harden, while the steels which do air-harden need to be rehardened from the correct temperature (920 - 950°C for stainless steel) and tempered to give toughness.

The recrystallization brought about by this heat-treatment may be illustrated by a taper-heated piece of steel, which was

made to have a coarse fracture by prolonged heating at a high temperature, then subsequently reheated near one end to the correct normalizing temperature (see Fig. 7).

Apart from consideration of resistance to shock and other physical tests of like nature, there are other reasons why stainless steels of the type under consideration would be benefitted by heat treatment.

The corroded band shown on the knife (Fig. 8) is such as may be seen in the earlier stages of its development by keen observers in many cafés and hotels up and down the country. It is there because the material in that region is soft when compared with the other parts of the blade. The band is soft because the cutler who made the knife soldered or brazed the metal handle on to the hardened blade, and during that operation heated the material about the bolster to or above the hardening temperature with the result that the heat ran down the blade and tapered off, leaving some hard and some soft parts.

Such knives will be put on the market and bear the name "stainless." Under domestic conditions the knives may live up to this name, but under more severe conditions in some cafés or hotels they may show marks or stains or even pitting. In any case the soft band is usually seen because it is more easily scratched than the harder surrounding material. Some knives in a factor's basement store, which developed corroded bands during the recent floods in the Thames valley, are shown in Figure 9.

The heat treatment affected the resistance to corrosion of stainless steel has been known for some time. The inventor, Mr. Brearley, knew this -- in an historical note he says, "We found that, of the specimens prepared for microscopic examination, some of the softer pieces etched with the usual laboratory etching reagents and some did not. Those that did not etch were in the hard condition, those that etched were soft." This observation has been confirmed by treating pieces of varying hardness with vinegar, a test reagent favored by cutlers. The resistance to staining by vinegar decreases with increasing tempering temperatures.

It may be noted that the cutler in Sheffield coined the name "stainless" for the steel which Mr. Brearley discovered for him. What the cutler meant was that the knives he prepared were unstained after subjection to tests in vinegar, lemon juice and other reagents such as would be met in domestic use. The steel may not have done so well had the cutler not been making a cutting tool; he must needs have the steel hardened to retain its cutting edge, and polished, to make it a salable article. Hence he did all the inventor required -- hardened and tempered and polished to give a clean metallic surface.

Thus, the word "stainless" coined by the cutler may be misunderstood. Stainless steel has different degrees of resistance to staining or corroding according to the heat treatment it has had and also its composition.

Generally speaking, the higher the chromium content the better the resistance after all treatments, and in the lower chromium stainless steels, i.e., 12-14 per cent, the harder the condition the greater the resistance. In the following notes when comparisons are made, they relate to the differences among stainless steels only and are not compared with ordinary mild steels, as the resistance of the lowest chromium stainless steel in its worst condition is many times more resistant than ordinary steels.

To return to the question of corrosion about band of material adjacent to heated parts, such as may result from brazing or welding, we may examine Figure 10. This bar was prepared to show that the corrosion was associated with softer material and this is well brought out by including the Brinell hardness impressions. The material used in the experiment was a bar of stainless cutlery steel prepared as follows: A length of about 12 inches was heated throughout at 950°C , and allowed to cool in air, which hardened it. One end was then placed in the heated furnace and allowed to attain the same hardening temperature while the other end was comparatively cool. Hardness measurements taken at short intervals along the bar show, by reference to previously determined hardness figures, to about what temperature the different parts of the bar attained on the second (taper) heating. We know that when hardened stainless steel is tempered there is a little falling off in hardness up to 500°C ,

but above that temperature the hardness falls very rapidly, so that we estimate that the temperature of the corroded part of the bar had reached 550-600°C.

Such soft places in bars of stainless steel may be found by an etching process using a solution of ferric chloride containing about 1 per cent of the salt in water. Used on the knife blade previously shown corroded (Fig. 8) we get the effect shown in Figure 11 after 10 to 15 minutes immersion.

Figure 12 shows a similarly etched piece of hardened stainless steel, which had previously been hardened and then locally heated by an oxyacetylene torch prior to polishing and etching. The parts heated hot enough to harden are light, but where the temperature was less and the plate was only softened, the etching is much quicker and shows darker in the photograph - note where the long heated band has softened the previously heated shorter bands.

If a number of bars which have been air-hardened and then tempered at temperatures between 200 and 700°C, are etched by immersing to half their depth in ferric chloride solution, they will show again that the softer material etches more quickly.

All these observations are of obvious importance to the welder, who must of necessity heat material locally about the parts to be welded. They show that he must take account of the effects of the heating and cooling of material on the physical properties of the material he welds. If this be stainless steel

of the type described up to now he may reasonably ask "Is there no better material than this, which may be less susceptible to the effects of local hardening and cooling both with regard to mechanical properties and resistance to corrosion?" The steel-maker has other alloys to offer, hence the reason for the title of this paper referring to stainless materials, and it may be well to indicate some of the reasons for the introduction of other types of stainless steel. Following the Great War, many engineers turned to stainless steel as a material which, under laboratory conditions, showed itself ideal for many purposes, and large quantities were made up into pumps, valves, etc. In many cases the results were strikingly successful; in other cases marked corrosion occurred, particularly where the stainless steel had been in contact with brass or bronze, or packings which contained an admixture of graphite in their make-up, and had been working in sea water. The result of contact between graphite packing and a pump rod of stainless steel is shown in Figure 13. The effect is due to electrochemical action - intensified by using very impure water.

Fortunately, the steel-maker is ready to learn from his troubles, and experiments indicated that a higher chromium content lessened these types of corrosion. Figure 14 shows the result of an experiment in which alloys containing different amounts of chromium were placed in contact with a bronze plate and immersed in sea water. The picture shows that part of the

alloy which was in contact with the bronze for a prolonged period. The amount of corrosion decreased with increasing chromium content and the specimen containing 16 per cent of chromium was unaffected. The obvious solution of the pump maker's trouble was to give him alloys containing 16 per cent or more of chromium, but unfortunately while such a high chromium content may do all that is required to give resistance to corrosion, such high chromium alloys do not harden very appreciably on quenching and are also lacking in toughness. There is, however, a use for this class of material where hardness and great toughness are not essential. It is fairly soft and ductile and may be cold-worked with ease. From the welder's point of view it is not an ideal material, because though it can be welded quite easily, the welded joints are comparatively fragile; they become coarse owing to the high temperatures at the weld, and cannot readily be refined.

There would have been very little call for such high chromium material had not the steel-maker discovered that the addition of small amounts of nickel would make it respond to heat treatment, and bring it into line with the hardenable stainless materials previously referred to. Such a modified high chromium steel, for example, makes an admirable pump rod. The usefulness of such steels, which are sold under the name of "Twoscore," has been repeatedly proved. In one notable instance, bronze rings were tightly pressed into contact with polished bars of various alloys containing relatively high chromium and small

amounts of nickel, and hung between high and low water levels on one of the piers on the coast. Figure 15 shows the rings removed from their original positions after six months under these conditions. All the bars were unaffected.

"Twoscore" steel has been extensively used in the seaplane industry, because of its high resistance to corrosion in sea water, good range of mechanical properties, and on account of the fact that it is readily welded by the oxyacetylene method, which is much used in the production of the various fittings for seaplanes.

Being an air-hardening steel welded parts of "Twoscore" will suffer many of the disadvantages due to making high temperature joints, and for that reason all welded parts of aircraft are rehardened and tempered after welding, for the obvious reason that the material must have definite mechanical properties on which the designer has based his calculations, and be able to resist the bending and other stresses which it will have to meet in service.

Whether this "Twoscore" material is better or worse than the lower chromium steels after welding when it is not given any after-treatment is a question which at once arises and so far as mechanical properties are concerned has been dealt with. With regard to corrosion: The results of some experiments on taper-treated pieces, prepared in a similar manner to that referred to in Figure 10, make it clear that "Twoscore" steel is immune from

the localized corrosion which is so noticeable in the ordinary stainless steels under the salt water conditions. Additional evidence was obtained by taking separate pieces of cutlery quality and "Twoscore," which had been air-hardened and tempered at various temperatures. The results plotted in Figure 16 represent the losses in weight after 30 weeks' immersion in sea water at room temperature (the samples were cleaned and the brine changed every week during this period).

The curve for the cutlery quality stainless steel is interesting in showing that the attack is greater when the steels were tempered at 550°C and not when fully tempered at about 700°C .

It does not, of course, follow that the hardened and tempered "Twoscore" is as resistant under all conditions as the same steel full-hardened. The experiments do indicate, however, the superiority of the steel as compared with the ordinary type of hardenable stainless steel.

Austenitic Steels

About the time Brearley was introducing the high chromium steels to the cutlery industry of Sheffield, Krupps in Germany were working with materials of similar or perhaps a little higher chromium content, but distinct from the Brearley group in that Krupps added sufficient nickel to make the steels austenitic. Such steels cannot be hardened and tempered by the usual heat treatment processes in the same way as the steels mentioned in

the preceding section; on the contrary, by quenching from suitable high temperatures they are softened. The quenching temperature for softening varies with the composition from 1000-1200°C. Probably the best known of this group are "V2A," "Staybrite," and "ANKA," the two latter being manufactured in this country. The chromium content varies from 16-20 and the nickel 6-12 per cent, and in some modifications smaller percentages of molybdenum and copper are added.

Brief reference may be made to the outstanding characteristics of this type of alloy:

(a) Mechanical tests of fully softened material:-

Yield point	15-20 tons (2240 lb.) per sq.in.
Ultimate strength	40-60 " " " "
Elongation	40-60 per cent in 2 in.
Reduction of area	50-60 " "
Impact	100 ft. lb.

It will be noted that the yield point is low, which makes the material unsatisfactory for many engineering structures. The tendency for "creep" under sustained low stress is also against the use of the material for stressed parts. The yield point and the ultimate strength may, however, be increased by cold working (rolling or drawing) and from the point of view of strength the steels are perhaps more often used in the cold-worked condition with a yield point of 50 tons per square inch and a proof stress

of only a little less.

The high values for elongation and reduction of area suggest that the material may be very ductile and capable of being cold-drawn or pressed to a great extent. It is true that very deep pressings may be made without rupturing the material, but it hardens very rapidly when cold-worked and the induced hardness is such that the operation of deep pressing requires powerful machinery. Figure 17 shows a comparison with some other alloys in this respect. The observations were made by cold pressing cylinders measuring .625 in. diameter by .950 in. long under a testing machine and noting the load required and the increase in Brinell hardness.

(b) Resistance to corrosion.

The austenitic alloys are generally considered to be more resistant to all forms of corrosion than the straight chromium steels - so far as mineral acids such as sulphuric and hydrochloric are concerned this is true, although the material is not by any means immune from the attack of either. The addition of 2 or 3 per cent of molybdenum helps resistance to sulphuric, while copper helps in the same way towards the attack of hydrochloric acid. The austenitic alloys are practically unaffected by nitric acid, which is also true of the straight chromium steels containing 15 per cent or more chromium.

The resistance to attack by the weaker organic acids is also

greater than in the case of the hardenable chromium steels; indeed, some of the acids (acetic, citric, oleic, and carbolic) have little or no effect. In other instances the rate of attack is so slow that the life of sheets in a chemical plant may be measured in years instead of months as is the case when mild steel is used.

Other characteristic properties of the austenitic alloys are:

- (c) Nonmagnetic.
- (d) High coefficient of expansion.
- (e) High electrical resistance.

The welding of the austenitic alloys does not present any serious difficulties; the material has a lower melting point than the chromium steels, it is much more fluid when molten and consequently fills joints well when gas welding is practiced.

As previously indicated, the material softens when cooled rapidly from high temperatures, so that little or no trouble would be expected to develop by the local heating and cooling during the welding. There is, in fact, no marked falling off in mechanical properties; welded sheets may be bent double along the weld without failure. Figure 18 shows a gas-welded "T" tube and Figure 19 the same tube after flattening. There is also a mass of experience indicating the success of welded objects in the chemical industries. On the other hand, there are a lesser number of failures, and it is from the examination of these

that we may learn and hope to suggest such remedies as will offset or possibly completely eliminate the causes from which they arise.

Figures 20 and 21 show photomicrographs taken near the welded joint of a vessel which failed rather unexpectedly in a large chemical works. The microphotograph (low power 50 diameters) shows the whole of the defect passing through the sheet. The higher power (100 diameters) microphotograph was taken at the starting point of the defect. The failure is remarkable in that it has led to separation along the grain boundaries.

Such is the resistance of this austenitic type of material to various corroding media that laboratory attempts to reproduce the type of defect shown in Figures 20 and 21, met with repeated failure and while so far as the author is aware, no attempts have succeeded in producing an attack so intergranular that a taper heated bar would fall into two pieces, research has shown that selective attack will occur on bars which have been heated to a welding heat locally and then allowed to cool. A couple of bars so treated and then exposed to the attack of a cold 20 per cent solution of copper ammonium chloride are shown in Figure 22. The square bar was heated with a blowpipe flame at the end. The round bar was fastened in a butt welding machine and the current applied until the center portion was hot enough to melt a 950°C Sentinel pyrometer.

The next question which arose was "What reheating tempera-

ture produces this condition which shows a decrease in the resistance to attack?" This was explored by means of taper-heated bars, the temperature at various points being judged in some instances by "temper colors," in others by means of the well-known "Sentinel" melting point pyrometers. The experiments indicated that the trouble is brought about by reheating in the range 750-850°C. Some confirmatory evidence that reheating an austenitic steel to a temperature about 800°C would cause a change in condition was available and is shown graphically in Figure 23. The increase in Brinell hardness, brought about by reheating pieces which had been previously softened, is very marked. It should be noted that this is not a type of steel met with in commerce. It contains too much nickel to be classed among the hardenable steels and not enough nickel to make it fully austenitic.

Most austenitic steels usually met with in practice contain more nickel (and chromium) than this steel, and as a result do not show anything like so great an increase in hardness on reheating. Often, in fact, no measurable change in Brinell hardness is produced. On such steels, however, heating to a temperature of 800°C is not without effect on the mechanical properties of the material as is shown by the following tests.

	YP. tons (2240 lb.) per sq.in.	US. tons (2240 lb.) per sq.in.	E. Elong- ation %	RA. Reduc- tion of area %	Impact ft. lb.
W.Q. 1000°C	16.8	54.8	56.0	58.2	100,102,98
Heated 24 hours at 800°C and cooled in air	18.0	60.4	31.5	47.2	62,56,56

It will be noted that the results are such as would be accepted as excellent by the engineer, although comparison shows slight increases in yield point and ultimate strength and a falling off in elongation, reduction of area, and impact, in the piece heated to 800°C.

Another interesting feature is observed in specimens prepared for micro-examination. In the first place the pieces heated to about 800°C etch very rapidly (requiring only about one-twelfth of the time necessary for the fully softened material). Further, the grain boundaries are easily seen in the pieces heated to about 800°C.

Figure 24 shows a photomicrograph of fully softened ANKA which required etching for four hours in 15 per cent hydrochloric acid in methylated spirits to develop the grain boundaries. Figure 25 shows similar material heated to 800°C; this required only 10 minutes in the same etching solution.

The effect of reheated fully softened austenitic steels would appear twofold. The carbides appear to fall out of solution and

migrate to the grain boundaries, while a change of state appears to occur in the crystals resulting in increased hardness. Figure 26 is a high power photomicrograph (750 diameters) showing specks of carbide at the grain boundaries in a piece heated at 800°C .

Researches into such questions are of little value unless they point to some remedial treatment, and observations indicate that heating to the usual softening temperature $1000-1200^{\circ}\text{C}$ will completely restore the austenitic alloys to the best condition to resist corrosion.

The foregoing deals with the materials for which there has been the greater demand, but it by no means exhausts the list of alloys in use, many of which have been made for the special requirements of a particular set of conditions in the various industries. Had it not been for the cooperation of Mr. Brearley with the cutlers of Sheffield the development of a domestically stainless cutlery might never have taken place and it is only by similar cooperation of steel and alloy makers with those who fabricate and also those who use their products that the use of other stainless materials has developed so rapidly. Further experience and adjustment of composition may result in alloys which will better resist corrosive or other chemical action, but the sum of our experience to date is that all welded material of whatever composition is better when it has been subjected to some after treatment. In the case of air-hardening steels, the

best after treatment would be a rehardening and tempering, or failing this a reheating (tempering) to soften the hardened material about the weld. Where the object is too large to admit of heat-treating the whole, a local reheating by the torch would be advantageous where there is danger of local corrosion developing due to hard and soft material lying side by side, or failure due to air-hardening.

In the case of the austenitic high chromium and nickel alloys there would appear to be no alternative to that of reheating the whole of the welded structure when it is to be used under conditions which would attack those parts which have reached a temperature of about 800°C during the welding.

To turn now to the consideration of the conditions for welding: the material should be free from scale - all stainless materials resist oxidation and scaling up to fairly high temperatures, but when scale is formed it is very refractory. This means that it will not readily unite with fluxes to form slag which will rise and leave the metal clean to unite with the welding rod. Fortunately for the welder, the steel-maker usually supplies the material in the pickled condition.

Electric Resistance Welding

1. Spot Welding is carried out on many of the domestic articles made from stainless steels, e.g., fastening the handles of saucepan bodies and lids. Figure 27 shows a microphotograph through a spot weld.

2. Lap and Seam Welding has been carried out on various types of containers used in chemical industry and also domestic articles.

3. Butt Welding may be conducted in the usual machines. The electrical resistance of stainless alloys is higher than that of ordinary steels and when welding stainless steel to ordinary steel it is necessary to make the joint out of center, i.e., have a longer length of ordinary steel out of the contact grips. A photomicrograph of the junction of the butt weld of an ordinary steel and stainless steel is shown in Figure 28.

Arc Welding

This is practiced with the machines normally used for welding ordinary steel. Special electrodes are obviously necessary - the welding material must be as stainless or more so than the material to be welded. The electrodes may be a stainless rod or consist of layers of metals or alloys which will melt down to give an alloy of about the same composition as the stainless material to be welded. The latter are known as "synthetic" electrodes.

If the rod is stainless material it will be made up of:

- (a) A core of stainless alloy.
- (b) An outer wrapping of asbestos twine.
- (c) A binder mixed with a reducing agent such as ferromanganese, aluminum or calcium silicide.

"Synthetic" rods are of various materials depending on what is required on melting down. For a rod to melt to stainless steel the components may be:

- (a) An iron or mild steel rod.
- (b) A wrapping of asbestos cord.
- (c) A binder plus powdered ferrochromium and a deoxidizer.

For a rod to melt to a high chromium nickel alloy the following may be the make-up:

- (a) An iron or mild steel rod.
- (b) An electro-deposited layer of nickel.
- (c) An asbestos cord.
- (d) A binder plus powdered ferrochromium and a deoxidizer.

The deoxidizer is, in some instances, a fine aluminum wire wound on the metal rod before the asbestos cord.

Analyses of electrodes before and after melting down for welding show that there is a loss of chromium probably due to oxidation during the welding. Welding rods should, therefore, contain at least 1 per cent more chromium than is required in the weld.

The composition of the weld produced by any electrode is

determined to a greater or lesser degree by the skill of the welder. If the arc is kept long, the weld will be lower in chromium, due to oxidation. The arc should, therefore, be kept as small as possible.

Gas Welding

Special stainless welding rods are needed, but the synthetic type are not satisfactory. In the case of austenitic steels the welding rods should be the same as the material being welded.

In the case of the hardenable steels, including "Twoscore," two types of welding rods are available - one containing chromium 16-20 per cent and nickel 6-12 per cent, and the other chromium 16-18 per cent and nickel 20-25 per cent. The higher nickel makes the latter run very easily and penetrates the joint. It has a lower melting point which makes it safer and better to use for thinner material. A disadvantage, however, is that this welding material is slightly attacked by dilute nitric acid, so that its use is somewhat limited.

The condition of the flame is most important. The flame should be slightly reducing, i.e., carrying a slight excess of acetylene. Too much acetylene gives carburized welds, will be hard and brittle and less resistant to corrosion. Carburized austenitic material is shown on the left of the photomicrograph in Figure 29. The right of the picture shows good material.

Too little acetylene gives oxidized welds, which are spongy and brittle and will leak. The type of weld of which Figure 30

is a cross section is produced when the metal is oxidized during the process of welding and the particles of oxide sink into the molten material and react with the molten metal, producing gas which blows pear-shaped cavities. If sufficient gas is formed a hole is blown on the upper side of the weld, and it is almost impossible to get a satisfactory weld after this condition has been produced.

It is difficult to weld both sides of a sheet for a number of reasons. While welding one side the other is scaled and any attempt to weld it would be at least a partial failure owing to the difficulty of removing this by fluxing. This trouble could be gotten over by pickling or sand blasting or removing the scale by some other method of abrasion. Another difficulty would then present itself, because nearly all the welding of stainless alloys is carried out with high nickel-chromium austenitic alloys, which have a high coefficient of expansion, and during the second welding heat may cause enough expansion in the previous weld to rupture the joint.

Fierce flames should not be used when gas welding stainless steel, and for this reason it is usual to use jets which are a size larger than those used for ordinary steels of similar size.

We now give an abridged report of a subsequent discussion.

The welding of stainless material has been practiced for a long time, probably with more successes than failures, but in some instances, owing to the lack of knowledge of the properties of the many alloys which are customarily called "stainless," welded objects have not been put into service in the best conditions. An alloy of chosen composition in the best condition to resist attack under a particular set of conditions may be said to be 100 per cent efficient so far as our knowledge of metallurgy is concerned. Any departure from the best condition may mean 95 or 90 per cent efficiency. The authors may appear to have stressed the difficulties and failures, which may arise in welding, but always with the object of gaining recognition of these and stressing the desirability and means of attaining the 100 per cent efficiency.

D i s c u s s i o n

Mr. C. S. Milne said he was particularly impressed with the fact that not only had the marvelous things that could be done with stainless steel, but also every defect, apparently, that it could possibly have, had been pointed out. The fact that Messrs. Bull and Johnson were prepared to admit that their material was not a universal panacea indicated that they had real faith in it. He had been particularly interested in the

authors' photographs of stainless steel knives showing that at certain parts which had been subjected to certain temperatures a softening of the material had occurred and had led to corrosion. Welders were particularly interested in that, because they were bound to heat their material, and there must be a point, near to each weld, which was heated to the particular temperature which would produce softening, and he gathered that that was the point at which deterioration was likely to take place. It was interesting to note that one of the things that welders must do, when working with stainless material, was to heat-treat it after welding, in order to overcome the softening to which he had referred. No doubt there was a great future for stainless materials in the chemical industries, and he hoped that the members of the Association, as welders, would do their best to ensure that they could do what was necessary in the way of heat treatment.

Mr. Arthur Stephenson asked if the steel-makers had yet finished making stainless steel. The authors, he said, would no doubt reply that they had not. The bugbear of the welding industry, however, was that there were so many forms of stainless steel. When welders were asked if they could weld stainless steel they, in their turn, asked what sort of stainless steel; the reply was "stainless steel." Many people bought stainless steel under the impression that because it was called stainless steel it was stainless. That, however, was not the case, and

the authors had made that quite clear. It would appear that the austenitic steel was the best for welding but, unfortunately, the conditions in the chemical industry were such that the steel which had to be used was not always the best for welding. There were many articles which could be fabricated only by welding. Welders were often asked, when they could not weld an article, what was wrong with their process. The trouble, however, was not so much what was wrong with the process as what was wrong with the materials. The process was all right, and it rested with the steel-makers to provide a material which would behave itself when fused.

Mr. Geo. F. Mason said he understood that the softer the metal the more liable it was to corrosion, and that the harder it was the less was the likelihood of corrosion. He asked for confirmation of that.

Mr. Bull said that applied, of course, to the hardenable steels.

Mr. Mason said he was interested in ships' plates, and pointed out that if shipbuilders could get steel which would be impervious to corrosion there would be an enormous future for it. Discussing the authors' reference to the corrosion of rods, and so on, due to their contact with graphite packing, he pointed out that all packing nowadays was metallic.

Mr. Phillips, speaking on behalf of those using steel, par-

ticularly of the austenitic type, for the manufacture of chemical plant, said that the great difficulty of welding it and obtaining and maintaining the required physical strength in the weld and in the surrounding material had been more or less overcome. A point which was of great interest, however, was that of the relative effects of different methods of welding on the chromium content of the weld, and he asked for the authors' opinion as to the relative merits of the different methods as determined by the composition of the metal in the weld. The application of electric welding methods resulted in a loss in the chromium content. In certain cases that was not of great importance to the chemical plant manufacturer; the resistance of this class of metal to nitric acid attack, for instance, was so great that a small difference in composition was of no importance; but it was of importance, of course, when one had to deal with chemicals which had a more drastic effect on the steel. Acetic acid, for instance, definitely attacked stainless steel. Its effect upon the steel was very slight, and the steel could be used in contact with acetic acid if that steel were in the best condition. If the chromium content of the steel were reduced, however, it was possible that the steel would be less resistant, not merely because of the heat treatment to which it had been subjected, but also because of the change in its composition. Stainless steel was being used today in large quantities not only in contact with nitric acid, but also in contact with other acids,

alkalies, and all sorts of chemicals, for which purpose it had proved of very great value, indeed.

A Speaker, dealing with the problem from the manufacturing point of view, said that manufacturers were often asked to make particular articles in a particular steel as, for instance, Staybrite, and they bought the steel and manufactured the articles with it. The authors' photographs, however, appeared to show that the result of welding was to increase the size of the grains. The size of the grains could be reduced again, of course, by normalizing but, at the same time, that process might render the material more susceptible to corrosion and he asked the authors if that were the case.

Mr. A. Sokell said that his experience had been concerned particularly with the Staybrite type of steel, and he found that there was difficulty in getting thorough penetration, particularly with the light-gauge metal. It had been his business to approach people who were desirous of making dairy utensils, and he had found that while one could get a weld which was fairly good on the outside, there were always cavities left on the inside. He understood that the Ministry of Health would not pass utensils for use in dairies if such cavities were left on the insides, because the cavities formed receptacles for bacteria, and so on, and there was some difficulty in getting over that trouble. Various methods had been tried, both with and without fluxes,

but it did not appear that a satisfactory answer to the problem had yet been found. That difficulty did not appear to arise in the welding of the Staybrite type of steel of thicker gauge; it seemed to weld much better and more easily than the lighter gauge type, both with and without fluxes. Mr. Sokell also asked the authors for information as to the coefficient of expansion of stainless steel as compared with that of aluminum, brass, and other metals; he understood that the expansion of Staybrite steel was 50 per cent more than that of ordinary mild steel. Also, he asked for information as to the conductivity of stainless steel in relation to that of silver.

Mr. A. E. Shorter said that in the welding of special steels there were difficulties which were not sufficiently appreciated by the actual welders. Some welders, it appeared to him, tried to weld stainless steel which was altogether unsuitable for stainless steel welding, and he was very glad that the authors had emphasized the importance of having the right material for the class of welding which was being undertaken.

Mr. Coulson Smith asked if organic acids attacked only the austenitic chrome steel and not the pure chrome steel, and suggested that if acetic acid attacked only the steel which contained a little nickel, it would be better to use the other for chemical plant. Dealing with line corrosion, and the authors' statement that they had had great difficulty in obtaining an

etching reagent for some of the material, he asked whether they had ever attempted to use, instead of the cupro-ammonium solution, an alcoholic solution of picric acid or, say, ammonium persulphate. The authors had drawn lines of demarcation between the various stages of stainless steel; there was one stage at which it was attacked by oxidation, another at which it was attacked by acid, and another at which it was attacked by corrosion, and he asked where was the line of demarcation between corrosion and oxidation, if the attack were not acidic. They were both chemical phenomena, oxidation being analogous to corrosion. Dealing with the authors' reference to the attack of material which was in contact with bronze and graphite packing, he asked what the attack was due to; was it an electrolytic phenomenon? He also asked if all the chromium in stainless steel was carbonless chromium or whether it was ferrochrome; also, was the hardness due entirely to the carbon content or to the chromium?

Mr. Marsh said that if any one had mentioned stainless steel to him two years ago he would have replied that he would have nothing to do with it. A few years ago we had been told that stainless steel would provide the solution to all our problems. Stainless steel, however, was not stainless under all conditions, and in order to obtain good results one had to submit to the steel-maker the definite conditions under which the material had to work. As the result of his experience in the manufacture of articles constructed of stainless material, he was

now passing on his problems to the steel-maker; if that were done generally, and if we were in the hands of such able men as Mr. Bull and Mr. Johnson, he was confident that in two years or so we should certainly be of opinion that stainless material, or materials of that character, were going to solve many of the problems which had faced us for many years. Heat treatment played a most important part. Any problems that he (Mr. Marsh) had put to Mr. Johnson or to his chief, Mr. Brearley, with regard to this material during the last two or three years had been satisfactorily solved, and he felt confident that if others submitted their problems to the steel-makers they would receive assistance such as he had received.

Mr. Bull, replying to the discussion, said that his firm would be delighted to help in the solution of the various difficulties if the users would get into touch with them. It was true that in the hardenable materials there was a distinct danger of producing soft bands as the result of welding, or of producing, in the case of the austenitic material, the harder reheated bands, and that there was more liability to corrosion at those bands; hence the need for heat treatment after welding. In reply to Mr. Stephenson, he said the steel-makers had not yet finished making stainless steel. It was suggested by Mr. Stephenson that those who supplied the welding apparatus had done their part, but if they considered they had reached finality they were a very poor lot. The steel-maker, in the old days, had cheer-

fully accepted the responsibility for all materials he supplied; he was probably able to make so much profit in those days that he could supply new material without worrying about investigating complaints. That was not so today, however, and Messrs. Brown Bayley's Steel Works probably learned more from the investigation of complaints than from all their researches. He knew that the users of stainless materials were waiting for the steel-maker, but he urged them not to allow the steel-maker to be kept waiting for them to come to him.

With regard to the effect of the various methods of welding, he said his own experience was that there were right and wrong conditions for every method; it was also true that one man could not tie himself down to one method. There were many cases in which it was impossible to use anything else than gas welding, but there was a right way and a wrong way of using it. If we knew the right condition in which to make the weld, and the right way in which to use the apparatus, we could cut out every variable but one, and that was the variable due to the human element. That was allowed for by putting more chromium into the welding rod. His firm usually allowed 1 per cent of chromium to be lost in welding. In some conditions - in arc welding - 3 or 4 per cent might be lost, but that was the fault of the man using the welding apparatus, and not of the steel-maker. It was true that the loss of a small amount of chromium did not matter from the point of view of the attack of the steel by nitric acid,

but where acetic acid was used in contact with the steel the loss of chromium did matter. There was a definite attack on stainless steel by acetic acid. It was singular, however, that although vinegar contained 5 per cent of acetic acid, it did not attack stainless steel in the hardened condition, and the reason was that vinegar contained some colloidal organic matter in its make-up, the effect of which organic matter was to restrain the attack. Tests had shown that there was no attack by acetic acid on austenitic steels containing 16 per cent chromium and 8-10 per cent of nickel, and steels of similar type.

It was inevitable that grain growth resulted from the heating of austenitic nickel-chrome alloys for welding, and one could not recrystallize those alloys by a simple heat treatment; the only way to overcome the difficulty was to break down the crystal structure by mechanical work. There was a distinct advantage, from the point of view of corrosive resistance, in heat-treating a weld of that type, in order to take out the effects of tapered heating.

With regard to Mr. Sokell's difficulty in regard to the cavities behind the welds in thin gauge materials used for making dairy utensils, he said that Messrs. Brown Bayley's Steel Works, Ltd., supplied welding material which has a high nickel content, maybe as high as 25 or 26 per cent, the effect of which was to make it more fluid when melted and to reduce the melting point. This material was used for thin gauge material which had not to

be in contact with nitric acid, because it was attacked by nitric acid.

The coefficient of expansion of the straight chromium steels - the hardenable chromium steels - was just a little less than that of ordinary mild steel. The coefficient of ordinary mild steel was 0.000011. That of the Staybrite and ANKA types varied, because the two materials were a little different in composition, the mean coefficient of expansion between 20-600°C for the ANKA type being 0.000018, and for the Staybrite, 0.00002. Aluminum had a higher coefficient of expansion, and the coefficient of brass and silver were intermediate between those of Staybrite and ANKA.

An attempt to give data as to the attack of various media on stainless steels would involve a lengthy task, but if any of the members wanted definite information he would be glad to supply it by letter. With regard to etching materials, he said he had tried picric acid, and had found it to be practically hopeless on any type of stainless material. Ammonium persulphate was not of use for the particular type of attack he was trying to develop on taper-heated bars of austenitic steel.

The question as to where was the line of demarcation between corrosion and acid attack opened up a very wide field. It was necessary first to ask ourselves what corrosion was, and in its simplest sense it could be regarded as a breaking down of some passified layer of metal on the outside surface. He looked upon

corrosion as something which did break down that passified layer on the surface, and which tended towards local attack. He regarded acid attack as definite solution of the metal not locally, but over the whole sample. With regard to contact corrosion when stainless steel was in contact with bronze, he believed there was a definite galvanic action, which was very likely to be set up when a pump, for instance, was in contact with sea water or impure mine water, or even with tap water if it contained a lot of salts in solution.

With regard to the carbon content, he said his firm rarely made a stainless steel with a carbon content of more than 0.35 per cent, so that they were limited as to the amount of carbon they could have in the ferrochrome. He believed the highest carbon content in ferrochrome used in the electric furnace for making stainless steels was 1 per cent.

Replying to Mr. Marsh's remark as to the necessity for using steel in the best condition for resisting attack, he said it was the business of the steel-maker to tell the welder what he ought to do, and it was the business of the welder to do it. The steel-maker had to create markets for his products, so that he did try to supply the right steel for any particular job. Thus, when a customer ordered a certain quantity of stainless steel wire of a certain gauge, and was asked by the steel-maker what he wanted it for, he would appreciate that the steel-maker merely wanted to give him the proper steel for the job.

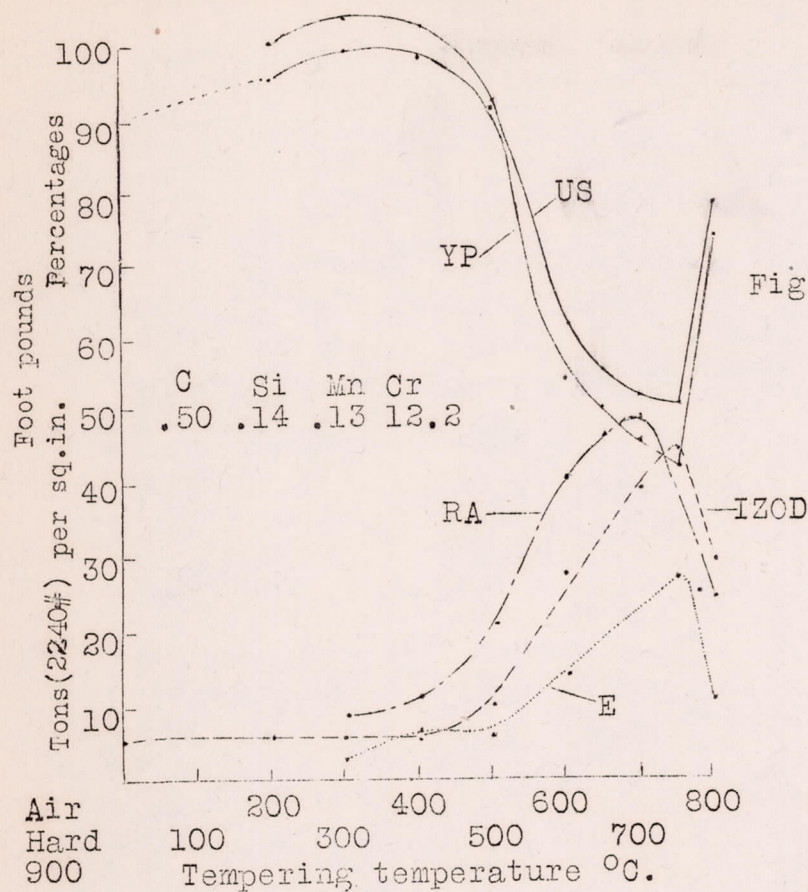


Fig. 1 Mechanical properties of hard stainless steel

RA, Reduction of area %
 E, Elongation %
 US, Ultimate strength
 YP, Yield point

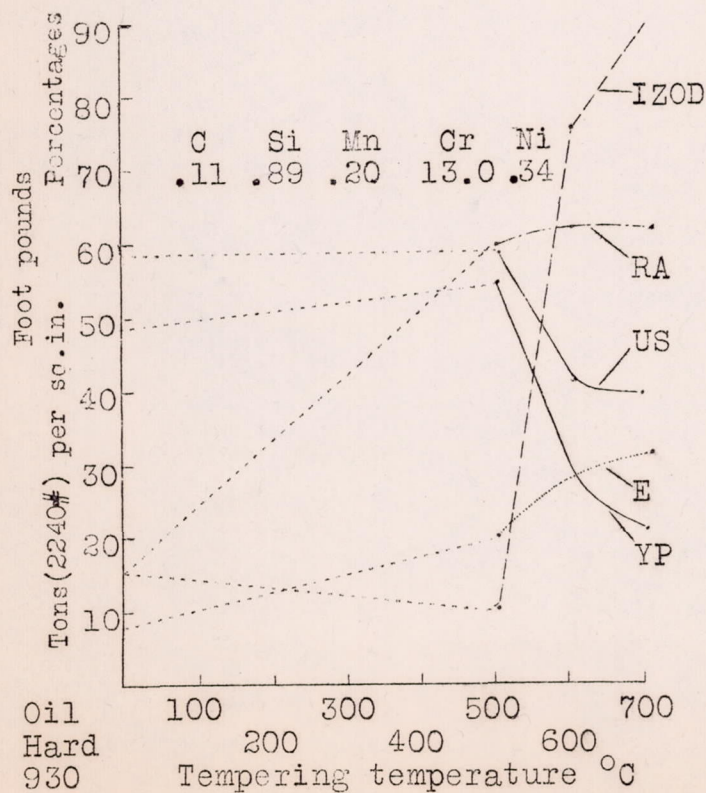


Fig. 2 Mechanical properties of stainless iron.

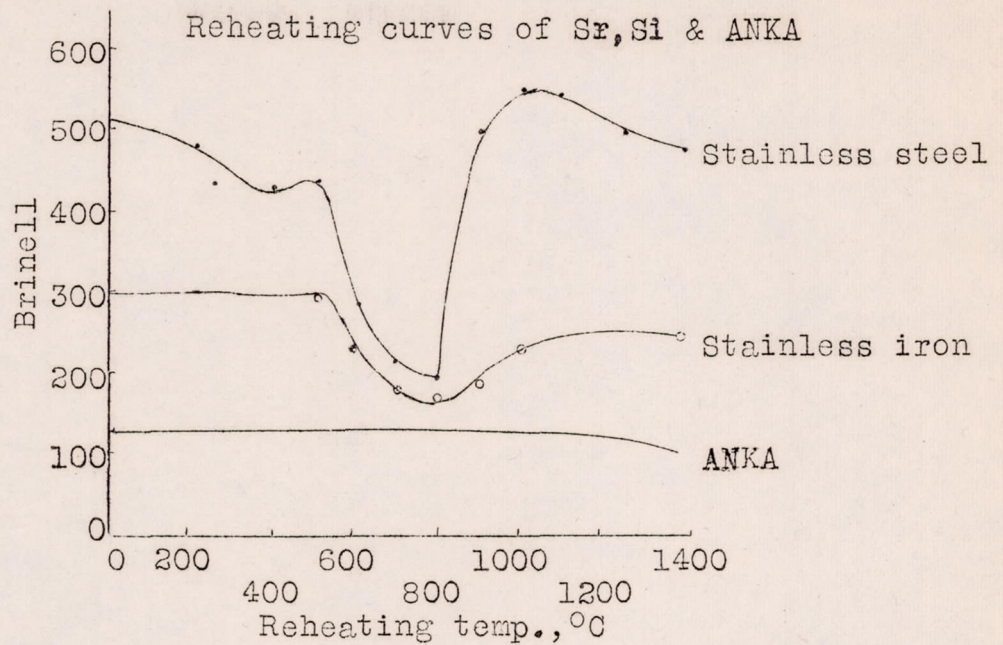


Fig. 3 Brinell hardness numbers of hard stainless steel, mild stainless steel (stainless iron) and ANKA. Cooled in air from reheating temperature.

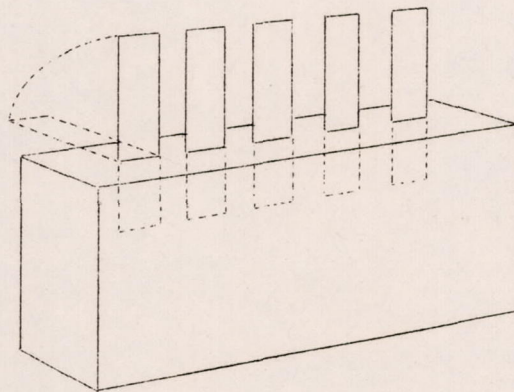


Fig. 4 Hard and mild strips of stainless steel in cast iron block



Fig.5 Turbine blade welded to retaining ring.

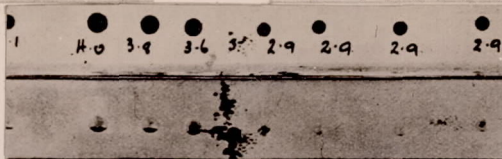


Fig.10 Corroded band on taper heated bar.

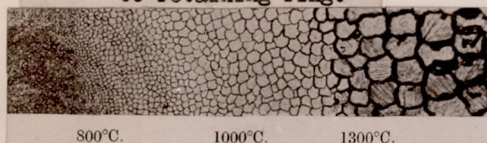


Fig.6 Illustrating crystal growth of metals on heating.

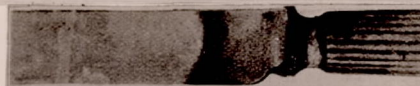


Fig.11 Knife etched in ferric-chloride to show soft band.



Fig.14 Stainless alloys after contact with bronze plate in sea water.



Fig.7 Fracture of coarse crystalline bar after refining.

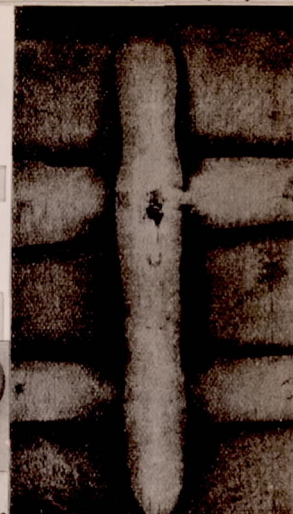


Fig.12 Stainless steel plate locally heated with blow-pipe (etched ferric-chloride).



Fig.8 Knife with corroded band near soft material.

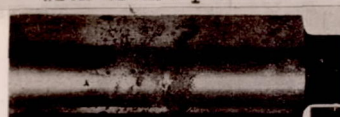


Fig.13 Corrosion on pump rod in contact with packing.

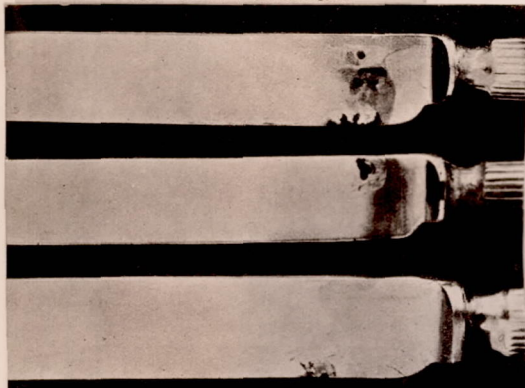


Fig.9 Knives with corroded bands produced in London flood (1928).

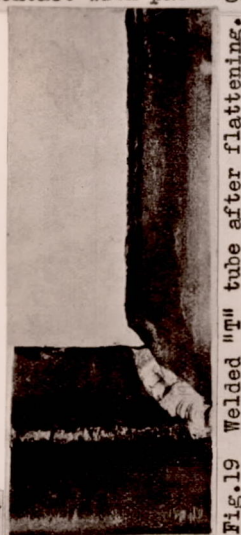


Fig.19 Welded "T" tube after flattening.

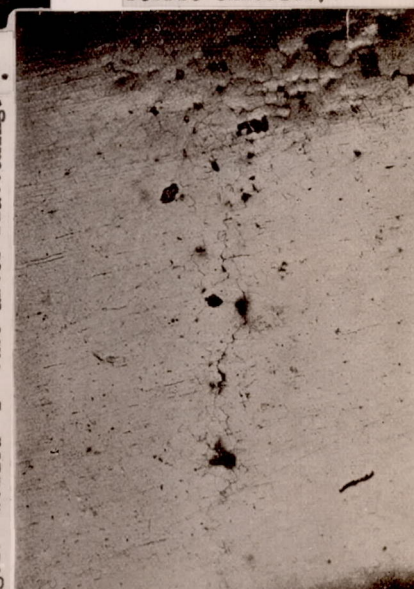


Fig.20 Photomicrograph of intergranular defect (50 dia.)

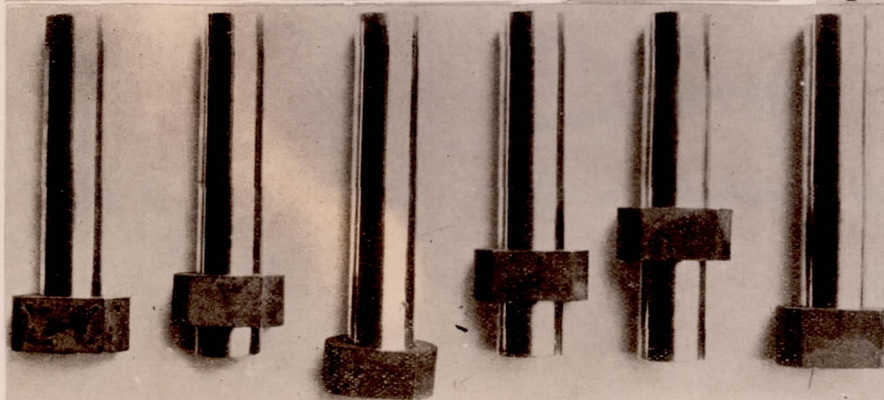


Fig.15 Stainless alloys with bronze rings after 26 weeks in sea.



Fig.18 Welded "T" tube.

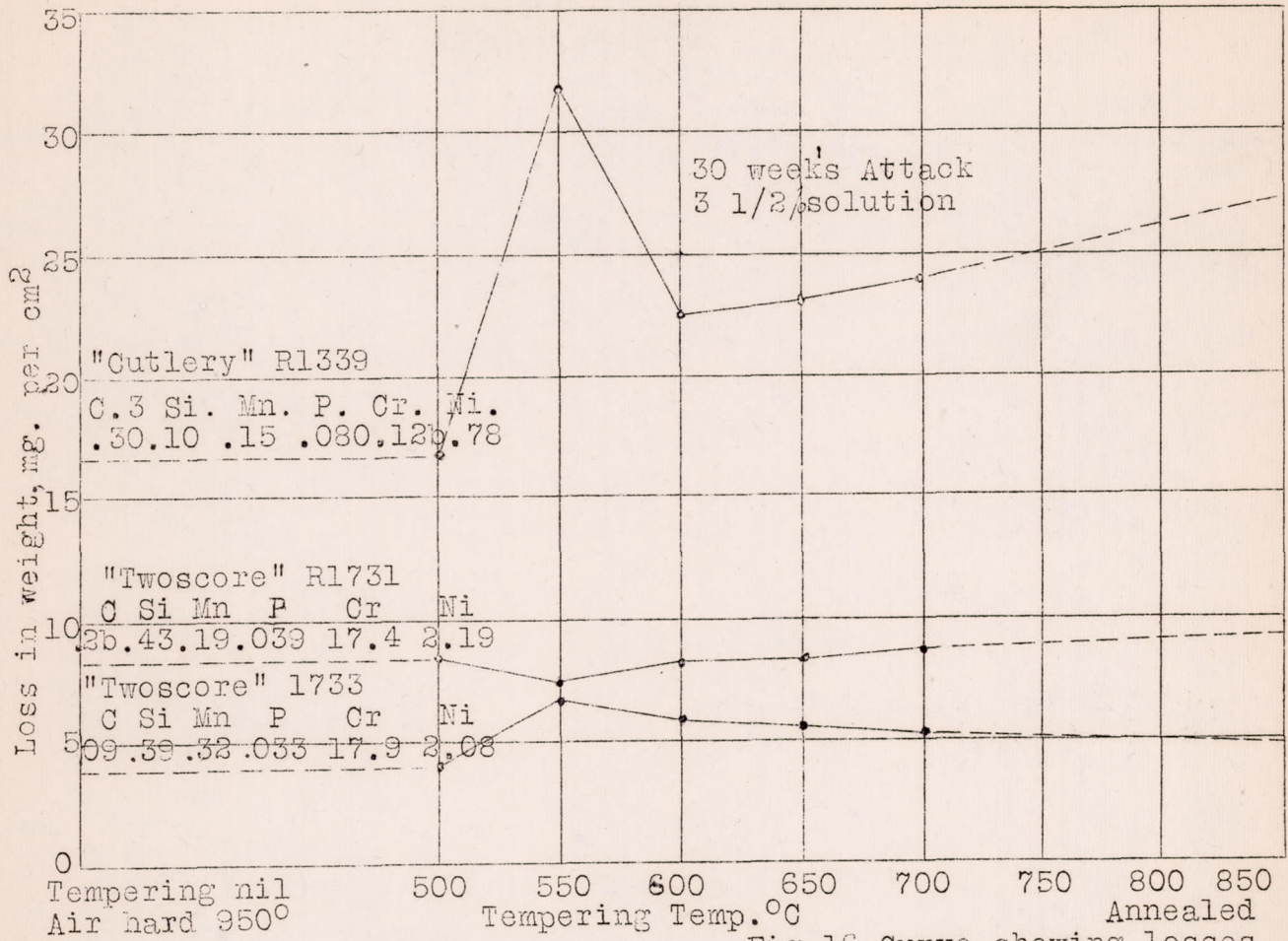


Fig.16 Curve showing losses in weight due to corrosion in sea water of stainless steel and "Twoscore"

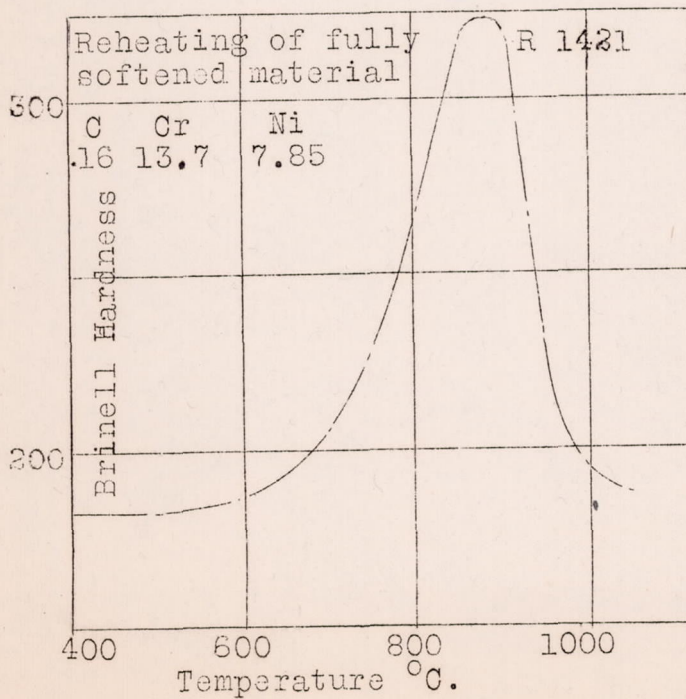
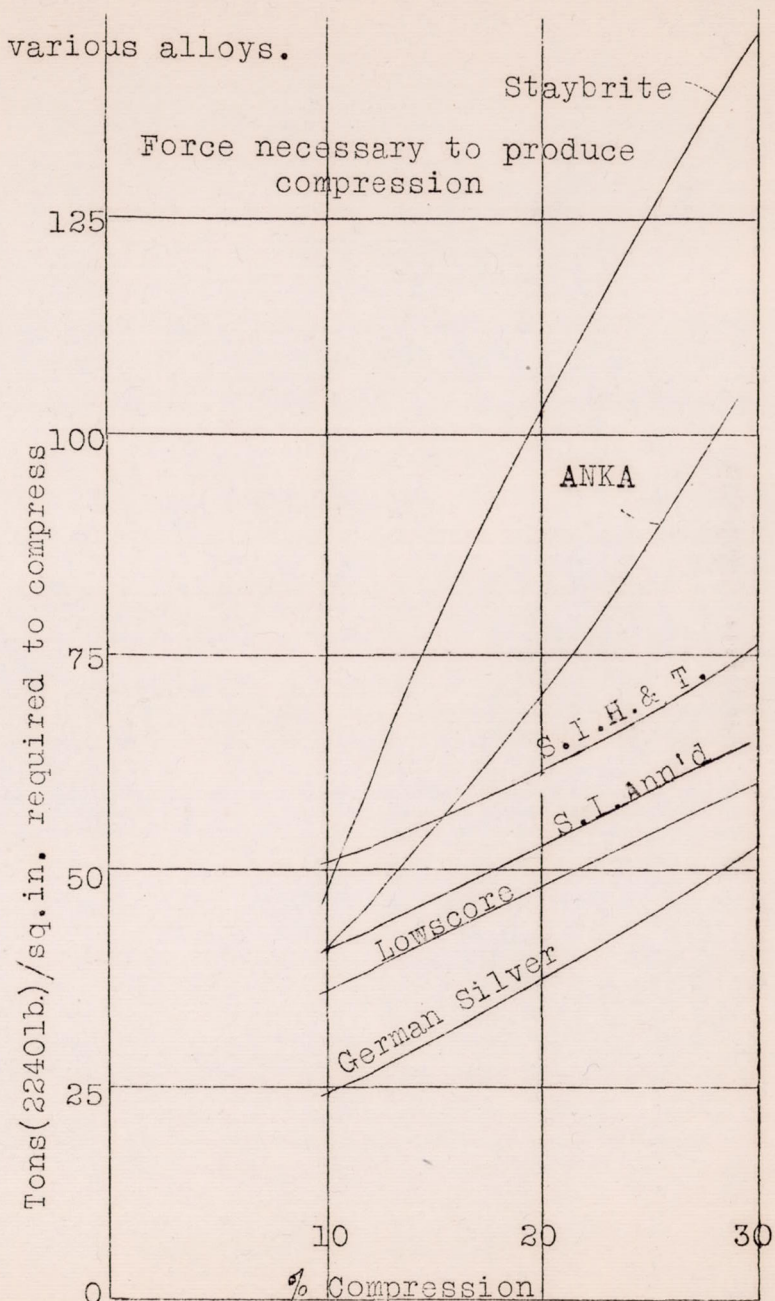
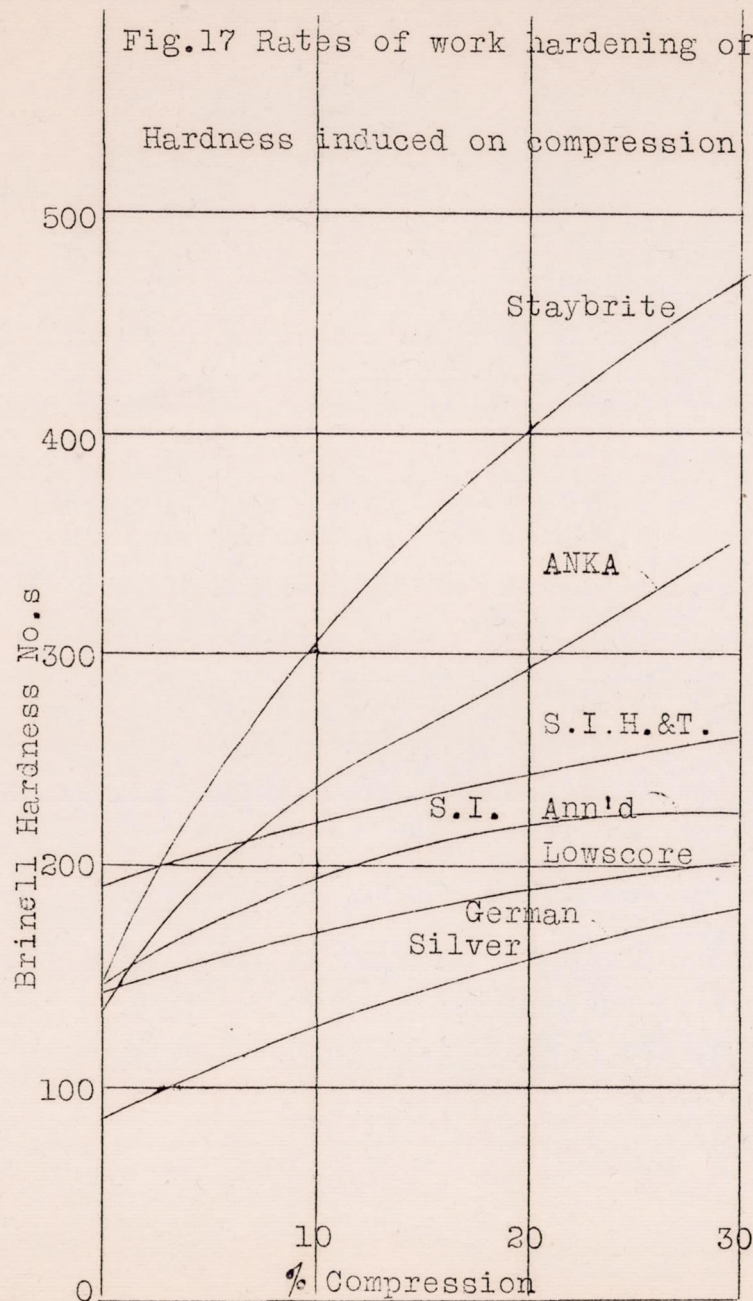


Fig.23 Graph showing increase in Brinell hardness on reheating previously softened chromium nickel alloy.



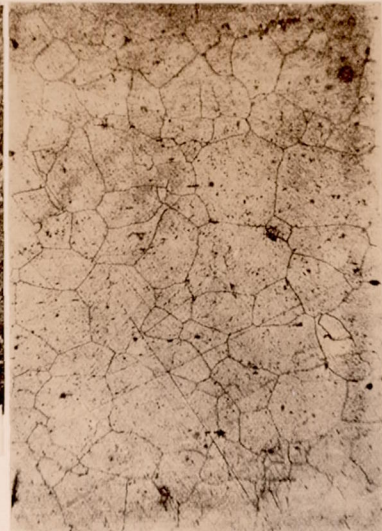


Fig.25 Austenitic alloy after re-heating to 800°C.(x 100 dia.)



Fig.21 As Fig.19 (x 100 dia.)



Fig.24 Fully softened austenitic alloy (x 100 dia.)

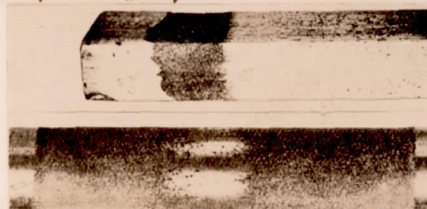


Fig.22 Taper heated bars of austenitic alloy.

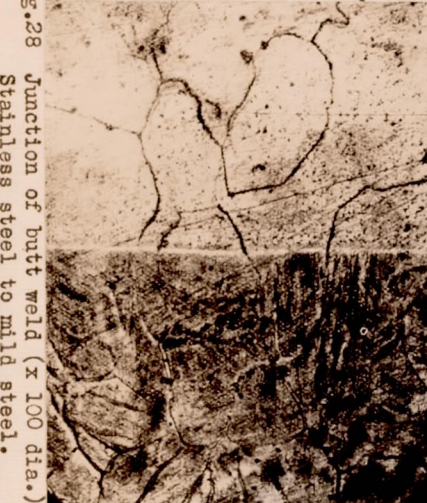


Fig.28 Junction of butt weld (x 100 dia.)
Stainless steel to mild steel.



Fig.27 Section through spot weld stainless iron (x 100 dia.)

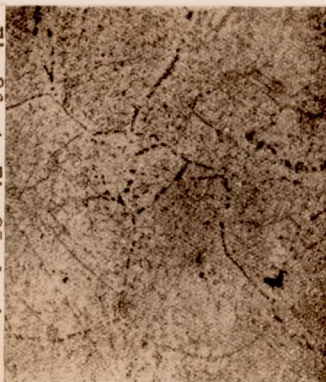


Fig.26 As Fig.25 showing carbide at grain boundaries (x 750 dia.)

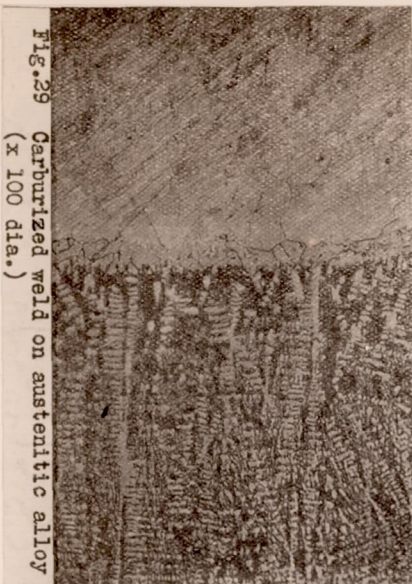


Fig.29 Carburized weld on austenitic alloy (x 100 dia.)



Fig.30 Oxidized weld showing blow-hole (x 50 dia.)